(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 734 771 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
20.12.2006 Bulletin 2006/51

(51) Int Cl.:
H04N 9/31 *(2006.01)* ***G02B 27/48*** *(2006.01)*

(21) Application number: **05012806.5**

(22) Date of filing: **14.06.2005**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR LV MK YU

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(54) Illumination optics, illumination unit and image generation unit

(57) The present invention relates to a laser illumination device (1) providing beam shaping and speckle reduction capabilities, and an image display system (1') using the device. This optical set-up is capable of transforming a laser beam or an array of laser beams into a shape which is adapted to uniformly illuminate the entire active area of an image modulator (100). At the same time it randomly disturbs the phase front of the beam in order to reduce the speckle contrast of the projected image, eg by providing a liquid crystal element (34') and electrode arrangement (35).

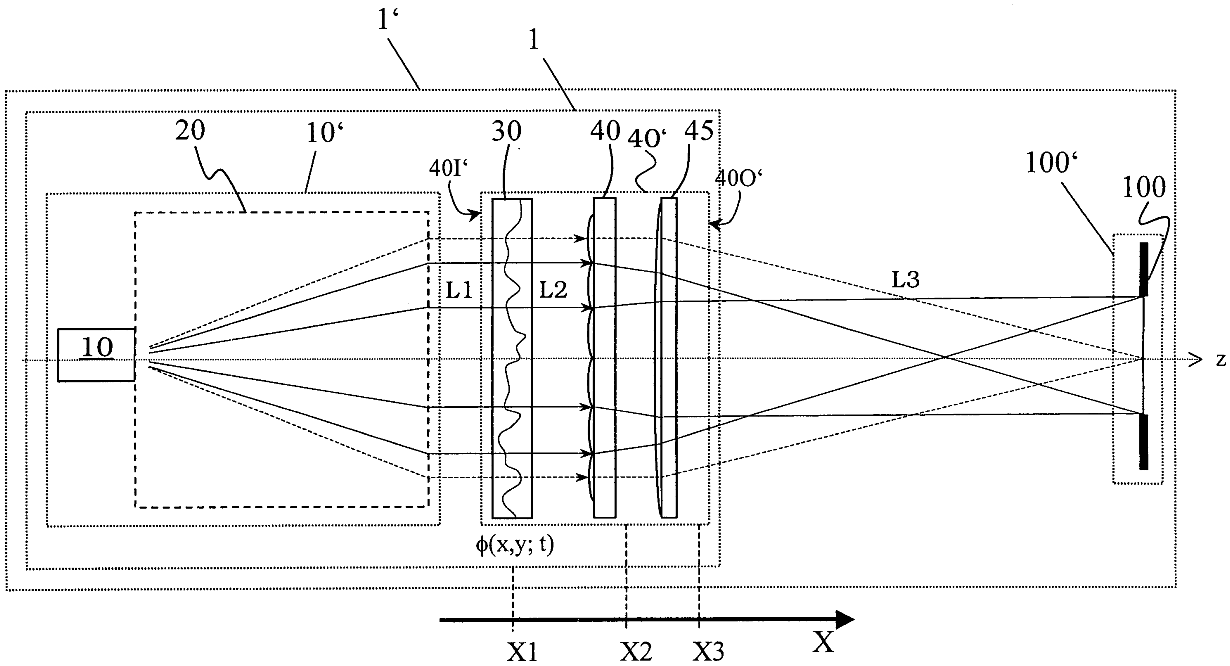

Fig. 2A

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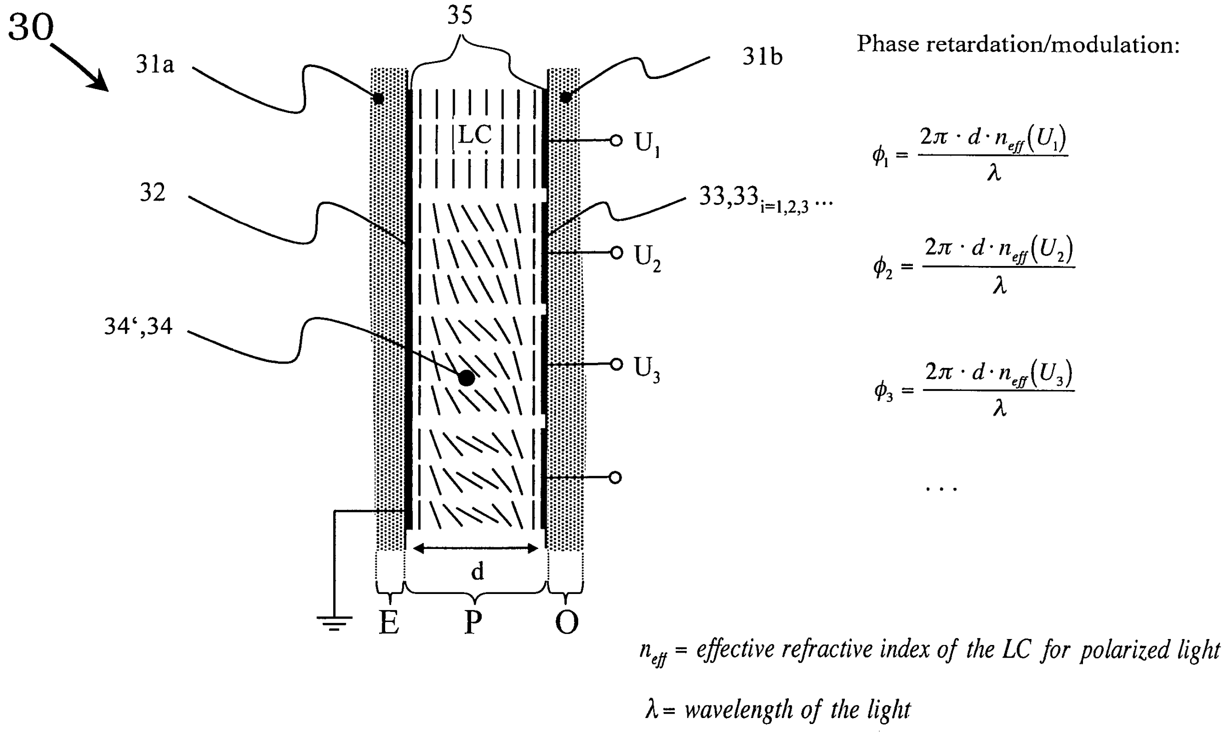

30
35
31a
31b
Phase retardation/modulation:
LC
U1
32
33,33i=1,2,3 ...
U2
34',34
U3
d
E
P
O
$\phi_1 = \frac{2\pi \cdot d \cdot n_{eff}(U_1)}{\lambda}$
$\phi_2 = \frac{2\pi \cdot d \cdot n_{eff}(U_2)}{\lambda}$
$\phi_3 = \frac{2\pi \cdot d \cdot n_{eff}(U_3)}{\lambda}$
...
n_{eff} = effective refractive index of the LC for polarized light
λ = wavelength of the light

Fig. 4

Description

Field of the Invention

[0001] The present invention relates to a light pre-processing optical element, an illumination unit and to an image generation unit. The present invention more particularly relates to laser illumination device providing beam shaping and speckle reduction capabilities, and image display engine using the device.

Background of the invention

[0002] Display devices become more and more important in electronic equipment and customer devices. Therefore, the technical development also focuses on processes and devices of illumination, image generation, and projection. It is a well-known problem that illumination devices and respective light sources do not only generate light in the respective channels with respective profiles and distributions but also tend to inherently produce some parasitic noise. These noise are called speckles in the field of laser light sources.

Summary of the invention

[0003] It is an object of the present invention to provide a light pre-processing optical element, an illumination unit, as well as an image generating unit which introduce at most a comparable reduced parasitic variational noise into the produced or used radiation or light.

[0004] The object is achieved by a illumination optics according to claim 1, by an illumination unit according to claim 21 as well as by an image generating unit according to claim 25. Preferred embodiments are within the scope of the respective dependent subclaims.

[0005] In its broadest sense according to the present invention a light pre-processing optical element is provided which is adapted in order to modulate a wave front of received primary illumination light to thereby generate pre-processed primary illumination light with a modulated wave front as secondary illumination light. Because of the introduced modulation of the wave front of said received primary illumination light the formally introduced parasitic noise is disturbed in order to at least reduce or avoid said parasitic noise completely.

[0006] Alternatively or additionally, the present can be understood as illumination optics which is adapted and which comprises means for independently and/or uncorrelatedly modulating wave fronts, phases or phase relation-ships of a plurality of parts or of a plurality of sub-beams of a beam of received primary illumination light L1 and for superimposing and/or recombining the thereby resulting respective independently and/or uncorrelatedly modulated parts or sub-beams to form secondary or tertiary illumination light as output light having reduced speckle noise properties.

[0007] According to the present invention a light pre-processing optical element is provided which comprises a light entrance section for receiving primary illumination light, the light pre-processing section for pre-processing said received primary illumination light in order to generate secondary illumination light as pre-processed primary illumination light and a light output section for providing said secondary illumination light. Said light pre-processing section is adapted and comprises means for modulating a wave front of a beam or a plurality of beams of said received primary illumination light to thereby generate said pre-processed primary illumination light with a modulated wave front as said secondary illumination light.

[0008] It is a further aspect of the present invention to provide an illumination unit which comprises a light source unit for generating and providing primary illumination light and a light pre-processing optical element according to the present invention for receiving said primary illumination light and for generating and providing pre-processed primary illumination light as secondary illumination light.

[0009] According to a further aspect of the present invention a projector arrangement is provided which comprises an illumination unit according to the present invention and an image modulator unit which is adapted, arranged and which comprises means for receiving illumination light and for generating and providing an image.

Brief description of the Drawings

[0010] The invention will now be explained based on preferred embodiments thereof and by taking reference to the accompanying and schematical figures.

Fig. 1 is a schematical block diagram elucidating the basic principle underlying the present invention.

Fig. 2A, 2B are schematical and cross-sectional side views for illustrating image generating units according to a first embodiments of the present invention.

Fig. 3A, 3B are schematical and cross-sectional side views for illustrating image generating units according to a second embodiments of the present invention.

Fig. 4 is a schematical and cross-sectional side view for elucidating properties of an embodiment of the light pre-processing optical element according to the present invention.

Fig. 5 is a schematical and cross-sectional side view for elucidating an embodiment of an illumination unit which can be applied in the present invention.

Fig. 6 is a cross-sectional side view of another embodiment for an illumination unit which can be applied in the present invention.

Fig. 7 is a schematical and cross-sectional side view for illustrating an image generating unit according to a third embodiment of the present invention.

Fig. 8 is a schematical and cross-sectional side view for illustrating an image generating unit according to a fourth embodiment of the present invention.

Fig. 9 is a cross-sectional front view elucidating some properties of a further embodiment of the light pre-processing optical embodiment according to the present invention.

Detailed description of the Invention

[0011] In the following functional and structural similar or equivalent element structures will be denoted with the same reference symbols. Not in each case of their occurrence a detailed description will be repeated.

[0012] In the following, it is generally referred to the accompanying figures.

[0013] According to the present invention illumination optics 40' are provided in particular for an image generation unit 1' which comprise a light input portion 40I' for receiving a beam of primary illumination light L1, which are adapted and which comprise means 30, P for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships of a plurality of parts or sub-beams of said beam of said received primary illumination light L1 to thereby generate respective parts or sub-beams of pre-processed primary illumination light L1' as respective parts or sub-beams of secondary illumination light L2 having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other, which are adapted and which comprise means for superimposing and/or recombining respective parts or sub-beams of said secondary illumination light L2 having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other in order to thereby generate a beam of tertiary light L3 having reduced speckle noise properties when compared to said primary illumination light L1, and which comprise a light output portion 40O' for providing said tertiary illumination light L3 as output light,

[0014] Said illumination optics 40' may be adapted and may comprise means 40, 41, 30, P for dividing said received a beam of primary illumination light L1 into said plurality of parts or sub-beams of said beam of said received primary illumination light L1.

[0015] In said illumination optics 40' said means 30, P for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships may be adapted for dividing said received a beam of primary illumination light L1 into said plurality of parts or sub-beams of said beam of said received primary illumination light L1.

[0016] Said means 30, P for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships may be provided as a light pre-processing optical element 30 or phase modulator 30 and in particular as a phase modulator 30.

[0017] Said light pre-processing optical element 30 or said phase modulator may comprise a light entrance section E for receiving primary illumination light L1, a light pre-processing section P for pre-processing said received primary illumination light L1 in order to generate pre-processed primary illumination light L1' as secondary illumination light L2, and a light output section O for providing said secondary illumination light L2, wherein said light pre-processing section P is adapted and comprises means for modulating a wave front and/or a phase relationship of a beam or a plurality of beams of said received primary illumination light L1 to thereby generate said pre-processed primary illumination light L1' having a modulated wave front and in particular a modulated phase relationship as said secondary illumination light L2.

[0018] Additionally or alternatively, in said illumination optics 40' said light pre-processing optical element 30 and in particular said phase modulator 30 may comprise a light entrance section E for receiving said beam or said plurality of sub-beams of said received primary illumination light L1, a light pre-processing section P for pre-processing said beam or said plurality of sub-beams of said beam of said received primary illumination light L1 in order to thereby generate a respective beam or a respective plurality of parts or sub-beams of a beam of pre-processed primary illumination light L1 as a respective beam or as a respective plurality of parts or sub-beams of a beam of secondary illumination light L2, and a light output section O for providing said secondary illumination light L2, wherein said light pre-processing section P is adapted and comprises means for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships of said plurality of parts or sub-beams of said beam of said received primary illumination light L1 to thereby generate said respective parts or sub-beams of pre-processed primary illumination light L1' as said respective parts or sub-beams of said beam secondary illumination light L2 having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other.

[0019] Said light pre-processing section P may comprise or may be formed by one or a plurality of liquid crystal elements 34' as wave front modulating and/or phase modulating elements.

[0020] Said liquid crystal element 34' may be formed as a plate-like structure and/or as a planar structure, in particular as a liquid crystal layer 34.

[0021] The arrangement formed by said light entrance section E, said light pre-processing section P and said light output section O may defines and form an optical axis Z, wherein said liquid crystal element 34' may define and form a normal axis and wherein said optical axis Z and said normal axis may be oriented parallely with respect to each other.

[0022] Said liquid crystal element 34' may be supported and/or framed by and between a first substrate 31a, in particular forming at least part of said light entrance section E and a second substrate 31b, in particular forming at least a part of said light output section O, in particular in a parallel manner.

[0023] Said first and/or said second substrate 31a, 31b may be formed as plate-like structures.

[0024] Said light pre-processing section P may comprise an electrode arrangement 35 of at least a pair of first and second control electrodes 32, 33 for exerting an electric field or voltage across said liquid crystal element 34' in order to set the liquid crystal element's optical properties in a controllable manner.

[0025] Said first control electrode 32 of said pair of said first and second control electrodes 32, 33 may be formed as a single and common electrode 32.

[0026] Said second control electrode 33 of said pair of said first and second control electrodes 32, 33 may be formed as an arrangement or as an array of independently controllable single electrodes 33i with i = 1, ..., M.

[0027] Said arrangement or said array of said independently controllable single electrode segments 33i; i = 1, ..., M of said second electrode 33 may define an according arrangement or an according array of liquid crystal element segments 34i; i = 1, ..., M of said liquid crystal element 34' or of said liquid crystal layer 34.

[0028] Said illumination optics 40' may comprise optical elements which are adapted and which are formed by or comprise means 40, 41 45 for receiving said secondary illumination light L2 from said light pre-processing optical element 30 and for generating and providing condensed secondary illumination light L2' as tertiary illumination light or output light L3.

[0029] The phase modulator 30 may be placed at any of the shown positions X1, X2, X2', X3 before, between, and after the optical elements 40, 41, 45.

[0030] Said illumination optics 40' may comprise a first lens array 40 of lens segments 40j with j = 1, ..., N which is arranged at the light output section's side of said light pre-processing optical element 30 and which is adapted and comprises means in order to receive said secondary illumination light L2 and in order to generate and provide an according number of N sub-beams of said secondary illumination light L2 as said tertiary illumination light L3 or a pre-form thereof.

[0031] Said illumination optics 40' may comprise a condenser lens 45 which is arranged in order to receive said sub-beams of said secondary illumination light L2 and which is adapted in order to focus said sub-beams of said secondary illumination light L2 in order to generate and provide said tertiary illumination light L3.

[0032] Said illumination optics 40' may comprise a second lens array 41 of lens segments 41j' with j' = 1, ..., N' which is arranged at the light output section's side of said light pre-processing optical element 30 and between said first lens array 40 and said condenser lens 44.

[0033] Said lens segments 40j with j = 1, ..., N and 41j' with j' = 1, ..., N' of said first and said second lens arrays 40, 41, respectively, may be formed and arranged in a one-to-one correspondence to each other, and according to said correspondence of said lens segments 40j, 41j' of said first and said second lens arrays 40, 41, respectively, a sub-beam of said second illumination light L2 may be generated by a given lens segment 40j of said first lens array 40 and its profile are imaged to a respective corresponding lens segment 41j' of said second lens array 41.

[0034] According to a further aspect of the present invention an illumination unit 1 is provided which comprises a light source unit 10' for generating and providing primary illumination light L1 and illumination optics according to the present invention for receiving said primary illumination light L1 and for generating and providing preprocess primary illumination light L1' as secondary illumination light L2 having a modulated wave front when compared to said primary illumination light L1.

[0035] The liquid crystal element 34' of said light preprocessing optical element 30 may be adapted and arranged in order to be completely irradiated by said primary illumination light L1.

[0036] Said light source unit 10' may comprise at least one coherent light source 10.

[0037] Said coherent light source 10 may be a laser light source.

[0038] Said light source unit 10' may comprise beam expander optics 20 which is adapted and which comprises means in order to expand said primary illumination light L1 for a complete irradiation of said liquid crystal element 34' of said light pre-processing optical element 30.

[0039] According to a further aspect of the present invention an image generation unit 1' which comprises an illumination unit 1 according the present invention and an image modulator unit 100' which is adapted, arranged and which comprises means for receiving illumination light L3 and for generating and providing output light L4 which is representative for an image I.

[0040] The aspects of the present invention and further aspects will be further discussed in the following:

[0041] The invention inter alia describes the illumination optical part of a projection system e.g. using a coherent light source such as a laser. A method is presented to transform one or a plurality of coherent light beams into a light beam — in particular with rectangular cross-section and flat beam profile — in order to illuminate the imager device(s) of a projection system efficiently and with uniform light distribution. A liquid crystal cell or LC cell is used in order to modulate the wave-front of the beam in order to reduce or destroy the coherence of the light, thereby suppressing the appearance of speckles in an generated and projected image.

[0042] Lens arrays — often in the form fly-eye lenses or integrator plates — are commonly used in projection systems in order to uniformly illuminate an image modulator. Laser projectors today are commonly realised by using one single laser beam for each colour or colour channel R, G, B which scans line by line over the screen (2D scanning projector). The image is generated on the screen by modulating the beam intensity synchronously with the line frequency. For the horizontal and vertical movement of the beam two scanning mirrors are used. Such kind of laser projectors with a single scanning beam are a potential safety risk for viewers, because in case of a malfunction of the scanning mirrors a static laser beam of high intensity is projected to the screen.

[0043] Another approach to use laser light in projectors is realized by the GLV (Grating Light Valve) technology. In such devices the laser beam is expanded to form a vertical line which is projected to a one dimensional image modulator (GLV chip). This GLV chip modulates the intensity of the reflected light to generate an vertical image line. The reflected light is projected to the screen and — by use of one horizontal scanning mirror — it is scanned over the screen. A full image is generated by changing the image content of the GLV chip synchronously with the horizontal scanning mirror.

[0044] Laser speckle is commonly reduced by the presence of a moving random diffuser or random phase retarder in the optical path, at a point where the laser is focused before the image formation device or at a plane where the image is formed in the optical systems: (see: Trisnadi in Proc SPIE 4657, 2002).

[0045] Today's projectors (data- and video-projectors) commonly use arc-lamps as light source. These lamps have several drawbacks: As these lamps emit white light, the light must be split into the primary colours (R, G, B) by the use of filters, which add size, weight and cost to the projection system. Moreover, light which is not within the spectral range of the primary colours is lost, thereby reducing the efficiency of the system.

[0046] Another drawback is the emission of IR- and UV-radiation. The IR-radiation produces heat and the UV- radiation causes degradation of organic components during aging.

[0047] The glass bulb containing the electrodes of the arc-lamp has an operating temperature close to 1000 °C and consequently has to be controlled and cooled by a forced air flow, which causes annoying noise.

[0048] Light emitted by high pressure arc lamps is unpolarized, which is a drawback when used in combination with polarizing image modulators like LCD (Liquid Crystal Display) or LCoS (Liquid Crystal on Silicon).

[0049] An important quantity in the design of projectors is the étendue (optical extent). In a simplified description the étendue is defined by the product of the cross-sectional area of a light beam with the beam divergence angle of that beam at a certain position. If a light beam is modified by an optical element, the étendue is preserved if the optical element was well-corrected or the étendue is increased if the optical element was not well-corrected. It is impossible to decrease the étendue of a beam by any kind of optical transformation, except the case where part of the beam is simply cut and light is lost. In other words, the image luminance can never exceed the source luminance. This has consequences for the design of projectors, as the optical elements in a projector have a limited size (this limits the beam cross section) and/or a limited acceptance angle (this limits the beam divergence angle). For example the projection lens has a certain f/# which limits the beam divergence angle. Moreover, the image modulators are limited by size (cost) and beam divergence angle: The bigger the beam divergence angle of a light beam the lower is the contrast of the modulated image. As a result, the étendue of the light source must be smaller than the étendue of the most limiting optical element in a projector. The étendue of a light source should be as small as possible in order to achieve compact projectors with good image quality (contrast, brightness).

[0050] An ideal projection lamp with zero étendue would be on one hand a point source (zero cross section, but high beam divergence) or on the other hand a collimated beam without divergence (any cross section but zero beam divergence). In reality the étendue of arc lamps is determined by the size of the arc. The minimal possible arc length is restricted due to the thermal stress of the electrodes which strongly influences the lifetime of the lamp. As a compromise, commonly used arc lamps today have arc lengths slightly below 1mm and lifetimes between 2000 and 6000 hours (dependent on power).

[0051] LEDs or light emitting diodes as light source in a projector can overcome many of the above mentioned drawbacks of arc lamps.

LEDs

[0052]

- emit inherently light in the wavelength range of primary colours (R, G or B).
- do not emit UV- or IR radiation.
- can be cooled passively or at least with a low air flow without generating fan noise.
- have potentially a long lifetime.
- can be driven in a pulsed mode for sequential color generation.

But there a still some drawbacks.

- LEDs emit unpolarized light, which is a drawback if used in combination with polarizing image modulators (LCD, LCoS).
- LEDs have a significant étendue (emitting light with a high divergence angle, usually like a Lambertian

emitter).

[0053] Laser light sources are very close to an ideal projection light source, as they can solve all of the above mentioned drawbacks of arc lamps and LED.

Laser light sources

[0054]

- emit inherently monochromatic light (R, G or B).
- do not emit UV- or IR radiation.
- can be cooled passively or at least with a slow air flow without generating fan noise.
- have potentially a long lifetime.
- can be driven in a pulsed mode for sequential color generation.
- emit inherently polarized light
- have extremely low étendue (close to zero).

[0055] Laser projectors today are commonly realised by using one single laser beam for each color (R, G, B) which scans line by line over the screen (2D scanning projector). The image is generated on the screen by modulating the beam intensity synchronously with the line frequency. For the horizontal and vertical movement of the beam two scanning mirrors are used. Such kind of laser projectors with a single scanning beam are a potential safety risk for viewers, because in case of a malfunction of the scanning mirrors a static laser beam of high intensity is projected to the screen.

[0056] Another approach to use laser light in projectors is realized by the GLV (Grating Light Valve) technology. In such devices the laser beam is expanded to form a vertical line which is projected to a 1-dimensional image modulator (GLV chip). This GLV chip modulates the intensity of the reflected light to generate an vertical image line. The reflected light is projected to the screen and — by use of one horizontal scanning mirror — it is scanned over the screen. A full image is generated by changing the image content of the GLV chip synchronously with the horizontal scanning mirror.

[0057] A third method to use lasers in projectors is to illuminate image modulating panels like LCD (Liquid Crystal Display) or LCoS (Liquid Crystal on Silicon) or MEMS (Micro-electromechanical Systems). In this case the image is completely generated by the image modulating panel and the laser light just illuminates the (rectangular) aperture of the panel. This is very similar to any standard projector which uses arc lamps for illumination. Several groups have proposed such kind of laser projectors but today no such product is on the market. DOEs (Diffractive Optical Elements) or refractive optical elements like micro-lens arrays are used for beam shaping to illuminate the rectangular aperture of the panel.

[0058] But due to the coherence and low étendue of laser beams another phenomenon is observed when projecting laser light to a screen: Laser light is scattered on the diffusing screen and a parasitic noise called speckle is observed. Laser speckle is commonly reduced by the presence of a moving random diffuser in the optical path, at a point where the laser is focused before the image formation device or at a plane where the image is formed in the optical systems. (see Trisnadi in Proc SPIE 4657, 2002). Another proposed method to reduce speckles is the use of acousto-optic diffuser plates (G. Bastian, GMM Workshop Mikrooptik in Karlsruhe, 3./4. Feb. 2005).

[0059] The quantity to describe speckle is the speckle contrast c, which is defined by $c = \sigma I / I$. (see J. W. Goodman in J. Opt. Soc. Am, Vol. 66, No. 11, November 1976). Here σI is the standard deviation of the intensity distribution of the pattern and I is the mean intensity of the pattern. In the worst case c equals 1 which means maximum noise of the image. In the best case c equals 0 which means a perfectly smooth ($\sigma I=0$) image.

[0060] The general idea to reduce speckle with moving or time-varying diffusers is to generate as many as possible different speckle patterns within the integration time of the detector (human eye). The superposition of N uncorrelated speckle patterns within the integration time gives a smoother image with a speckle contrast reduced by factor $\sqrt{N}$ (see J. W. Goodman in J. Opt. Soc. Am, Vol. 66, No. 11, November 1976). Example: 625 uncorrelated speckle pattern during one image frame (assuming 50Hz) are required in order to reduce the speckle contrast by a factor $25=\sqrt{625}$. This means 625 different and uncorrelated patterns must be generated within 20ms.

i) Now assuming a 2D scanning laser projector with 50Hz image frame rate and HDTV resolution (1920 x 1080 Pixel), the laser beam needs 9.6ns to scan over one pixel. As this occurs only once during the frame period of 20ms, the 625 different pattern must be generated within 9.6ns when the beam is passing the pixel. This translates to a pattern frequency of 64.8 GHz.

ii) In the case of a ID scanning laser (GLV), the laser beam needs approx. 10μs to scan over one pixel-line. With 625 different pattern during this period this translates to a pattern frequency of 60 MHz.

iii) When illuminating an image modulator (LCD, LCoS, MEMS), then the laser light is continuously illuminating each pixel (except in the case where the laser is pulsed). In that case 625 different patterns must be generated during the period of 20ms which translates into a pattern frequency of 31.25kHz.

[0061] The conclusion from i) to iii) is, that speckle reduction by moving or changing diffusers is easiest in case iii).

[0062] Another method to reduce the speckle contrast is to use several laser light sources in parallel, e.g. laser array, where the lasers are incoherent to each other. If using N uncorrelated lasers then the speckle contrast again is reduced by factor $\sqrt{N}$ (see: J. W. Goodman in J. Opt. Soc. Am, Vol. 66, No. 11, November 1976).

[0063] The present invention inter alia describes an optical set-up which is capable to transform a laser beam or an array of laser beams into a shape which is adapted in order to uniformly illuminate the entire active area of an image modulator. At the same time it randomly disturbs the phase front of the beam in order to reduce the speckle contrast of the projected image.

[0064] A method is described for uniformly illuminating an image modulator and reducing the speckle caused by a coherent and collimated light source (laser), comprising: Beam expander and/or beam shaper or a combination of both to expand and/or shape a coherent light beam into a beam of larger cross-section and/or different shape. At least one lens array positioned in the light path of said expanded light beam, thereby producing a plurality of sub-beams, each of said sub-beams illuminating the image modulator. At least one liquid crystal cell or LC cell positioned in the light-path of said expanded beam and/or in the light-path of said sub-beams, which is adapted and/or arranged to change the director profile in the LC layer in a lateral and/or temporal manner, thereby disturbing the wave front of the sub-beams and thereby reducing the speckle contrast of the resulting beam when projected on a screen.

[0065] Instead or additionally, at least one moving or rotating diffuser could be used in which case the LC cell or liquid crystal cell would essentially not be necessary.

[0066] The coherent light beam can be an array or arrangement of coherent light beams which can be incoherent to each other and wherein said beam expander and/or beam shaper is adapted and/or arranged in order to expand and/or shape each of said coherent light beams of said array.

[0067] The beam expander and/or beam shaper may be adapted and/or arranged in order to form the beam into a shape which is congruent to said lens array.

[0068] The beam expander and/or beam shaper may be adapted and or arranged in order to illuminate said lens array with a uniform light distribution.

[0069] The beam expander and/or beam shaper may comprise at least one diffractive optical element in order to expand and/or shape the beam.

[0070] The beam expander and/or beam shaper may comprise at least one diffusing optical element in order to expand and/or shape the beam.

[0071] The DOE or diffusing optical element may be rotating or moving in order to reduce speckle contrast.

[0072] The beam expander and/or beam shaper may comprise at least one refractive optical element in order to expand and/or shape the beam.

[0073] The lens array may consist of a plurality of lens segments, each lens segment of similar shape like the imager panel (e.g. rectangular) and wherein the optical power of each lens segment is adapted that each of said sub-beams is illuminating the entire image modulator.

[0074] A second lens array may be used wherein each lens segment is adapted and/or arranged in order to image the corresponding segments of said first lens array as object onto the image plane of the image modulator.

[0075] Additional optical means, e.g. condenser lens may be used between the lens array(s) and the image modulator in order to superimpose each of said sub-beams to the image modulator.

[0076] Optical means, e.g. field lens may be used between the lens array(s) and the image modulator in order to form a telecentric light beam on the image modulator.

[0077] A narrow angle diffuser may be used in front of said first lens array in order to suppress interference artefacts, wherein the angular diffusion is adapted in a way that the sub-beams emerging from each lens segment on the first lens array entirely fill, but do not exceed, the aperture of the corresponding lens segment on the second lens array.

[0078] The narrow angle diffuser plate may be periodically and/or randomly moved in order to further reduce speckle contrast. The movement can be translational in any direction or rotational or any combination thereof.

[0079] The liquid crystal cell or LC cell may comprise an electrode pattern on one or both sides, wherein each electrode can be driven independently by a continuous or modulated voltage signal in order to change the director pattern of the liquid crystal layer, thereby changing the phase retardation in a spatial and/or temporal manner in order to reduce the speckle contrast of the resulting beam when projected on a screen.

[0080] The liquid crystal layer of said liquid crystal cell may be parallely aligned thereby having an uniaxial director profile with refractive index ne along the extraordinary axis and refractive index no within the plane perpendicular to the extraordinary axis.

[0081] The light beam may be linearly polarized and wherein the extraordinary axis is aligned parallel or perpendicular to the electrical field vector of the linear polarized beam in order to keep the polarization state unchanged when passing the liquid crystal layer.

[0082] The shape and position of the electrodes of said liquid crystal cell may be congruent to the shape and position of the lens segments of said first lens array in order to control the phase retardation of the sub-beams emerging from each lens segment individually and independently from each other.

[0083] The electrodes of said liquid crystal cell may be replaced by several sub-electrodes, wherein each of them can be independently driven by a continuous or modulated voltage in order to further reduce the speckle contrast of the system.

[0084] The present invention inter alia describes an illumination unit of or for a projector and takes advantage of laser light sources, but overcomes the commonly known disadvantages of laser light which are speckle contrast and safety risks to the eye. A method is disclosed which reduces speckle contrast without any use of moving parts and which on the same time achieves a homogeneous light distribution on the image modulator.

[0085] In the following reference is taken in more detail to the accompanying Figures which demonstrate details of preferred embodiments and of best modes for carrying out the present invention.

[0086] Fig. 1 demonstrates by means of a schematical block diagram some basic aspects of the present invention.

[0087] In Fig. 1 an embodiment of the image generating unit 1' according to the present invention is shown in a schematical way. The image generating unit 1' is formed by an embodiment of the illumination unit 1 according to the present invention which is adapted and which comprises means for generating illumination light, here in the form of tertiary illumination light L3. Said illumination light is received by an image modulator 100' which in turn forms image light or projection light L4 which is representative for an image I to be displayed. The embodiment for the illumination unit 1 comprises a light source unit 10' having at least one light source 10 for generating primary illumination light L1. Said primary illumination light L1 is emitted and irradiated to an embodiment of the light pre-processing optical element 30 or phase modulator 30 according to the present invention which is adapted and which comprises means in order to generate from said received primary illumination light L1 secondary illumination light L2 which is a pre-processed form L1' of said primary illumination light L1. The pre-processing includes a wave front modulation of said primary illumination light L1 and of one beam or a plurality of beams thereof in order to reduce or avoid parasitic optical noise due to the coherence of said primary illumination light L1. The embodiment for the light pre-processing optical element 30 or phase modulator 30 according to the present invention comprises a light entrance section E which is adapted for receiving said primary illumination light L1 from said light source unit 10'. Said primary illumination light L1 is then provided to a pre-processing section P which in turn performs the wave front modulation of said primary illumination light L1 in order to generate pre-processed primary illumination light L1' which is then provided as secondary illumination light L2 to a light output section O of said light pre-processing optical element 30 or phase modulator 30. Said light output section O is adapted comprises means for emitting and irradiating said secondary illumination light and for providing the same to illumination optics 40'. In said illumination optics 40' said received secondary illumination light L2 is made more uniform and then projected and focussed for further processing, for instance for providing said secondary illumination light L2 as condensed secondary illumination light L2' to said image modulator unit 100'. Said condensed secondary illumination light L2' is also referred to as tertiary illumination light L3.

[0088] Fig. 2A is a schematical and cross-sectional side view of a preferred embodiment of the image generating unit 1' according to the present invention.

[0089] In this embodiment the illumination unit 10' comprises a light source 10 which is formed by a laser source or an array of laser sources and which therefore produces a laser beam or an array of laser beams as said primary illumination light L1. The laser light is received by a expander optics 20 in order to expand the primary illumination light L1 in order to achieve a complete irradiation or illumination of the following light pre-processing optical element 30 or phase modulator 30. The light pre-processing optical element 30 or phase modulator 30 in the case of the embodiment of Fig. 2A acts as an location dependent and time-dependent phase modulator which modulates the optical phases ϕ of the laser beams or of the different cross-sectional parts of the laser beams as a function of the spatial coordinates x, y and as a function of time t. The following illumination optics 40' comprises a lens array 40 which divides by means of respective lens segments the expanded and phase modulated laser beams or laser beam into N different sub-beams by means of said respective N lens segments. By means of a following condenser lens 45 as a part of said illumination optics 40' the spatially separated sub-beams are then focussed onto a following image modulator unit 100' which comprises a respective image modulator 100.

[0090] All optical components of the embodiment shown in Fig. 2A are arranged along a common optical axis Z. Said optical axis Z is arranged perpendicularly or essentially perpendicularly with respect to the optical surfaces of said light pre-processing optical element 30 or phase modulator 30, said lens array 40 and said condenser lens 45.

[0091] A laser beam or an array of laser beams 10 is expanded by a beam expander optics 20. The expanded beam is divided by means of a lens array 40 into N spatially separated sub-beams. The sub-beams are focused by a condenser lens 45 to the image modulator 100. A phase modulator 30 is placed at a position within the expanded beam in order to disturb the phase of the transmitted light beam in an uncorrelated or random way in order to reduce the speckle contrast of the projected image. The lens array 40 comprises N different lens segments, wherein each of the lens segments has a rectangular shape with the same aspect ratio like the image modulator 100 in order to illuminate the entire active area of the image modulator 100. The resulting illumination distribution on the active area of the image modulator 100 is smoothed out by the superposition of the N sub-beams.

[0092] The embodiment of Fig. 2B is comparable to that of Fig. 2A except in that explicit beam expander optics 20 are missing the functionality of which is simultaneously realized by said light pre-processing optical element 30 or said phase modulator 30.

[0093] Fig. 3A is a schematical and cross-sectional side view of a preferred embodiment of the image generating unit 1' according to the present invention.

[0094] In this embodiment the illumination unit 10' comprises a light source 10 which is formed by a laser source or an array of laser sources and which therefore produces a laser beam or an array of laser beams as said primary illumination light L1. The laser light is received by a expander optics 20 in order to expand the primary illumination light L1 in order to achieve a complete irradiation or illumination of the following light pre-processing optical element 30 or phase modulator 30. The light pre-processing optical element 30 or phase modulator 30 in the case of the embodiment of Fig. 3A acts as an location dependent and time-dependent phase modulator which modulates the optical phases ϕ of the laser beams or of the different cross-sectional parts of the laser beams as a function of the spatial coordinates x, y and as a function of time t. The following illumination optics 40' comprises a lens array 40 which divides by means of respective lens segments the expanded and phase modulated laser beams or laser beam into N different sub-beams by means of said respective N lens segments. By means of a following condenser lens 45 as a part of said illumination optics 40' the spatially separated sub-beams are then focussed onto a following image modulator unit 100' which comprises a respective image modulator 100.

[0095] All optical components of the embodiment shown in Fig. 3A are again arranged along a common optical axis Z. Said optical axis Z is arranged perpendicularly or essentially perpendicularly with respect to the optical surfaces of said light pre-processing optical element 30 or phase modulator 30, said lens array 40 and said condenser lens 45.

[0096] The embodiment shown in Fig. 3A is similar to the embodiment shown in Fig. 2A. However, some additional means are provided.

[0097] First of all said illumination optics 40' additionally comprises a second lens array 41 which is positioned between said first lens array 40 and said condenser lens 45. The first lens array 40 comprises lens segments 40i with i = 1, ..., N. In the embodiment shown in Fig. 3A the second lens array 41 also comprises N lens arrays 41i with i = 1, ..., N. In the particular case of Fig. 3A the lens segments 40i of the first lens array 40 and the lens segments 41i of the second lens array 41 are geometrically arranged in order to achieve a one-to-one correspondence with respect to each other. That means that a sub-beam generated by a lens segment 40i of the first lens array 40 is imaged and focussed onto a distinct and fixed lens segment 41i of the second lens array 41.

[0098] Additionally, the image modulator 100' further comprises a field lens 90 in front of the image modulator 100 in order to generate from the produced N sub-beams with respective sub-profiles a common tele-centric beam for the image modulator 100.

[0099] In this further preferred embodiment a second lens array 41 is used to improve the illumination distribution on the image modulator 100. In that case both lens arrays are arranged and/or adapted in a way that the lens arrays are close to the focal plane of each other as described in Fig. 3A. In this case the beam profile at the position of the lens array 40 is divided by the (rectangular) shape of the lens segments 40i, i=1, ...N into multiple sub-profiles. Each sub-profile is imaged by the corresponding lens segment 41i, i=1, ...N and the condenser lens 45 to the image modulator 100, thereby superposing the N sub-profiles in order to achieve a homogeneous profile at the position of the image modulator 100.

[0100] It is further preferred to use a so called field lens 90 in front of the image modulator in order to obtain a telecentric beam, which is required by most image modulators 100.

[0101] The étendue of the light beam at the position of the image modulator 100 is defined by the size of the lens array 41 with half diameter ‚a' and the distance ‚L' of the condenser lens 45 to the image modulator 100. The étendue equals $E = \pi \times A \times \sin2(\vartheta)$, where A is the area of the image modulator 100 and $\vartheta = \arctan(a/L)$ is the divergence angle of the light beam at the position of the image modulator 100. It must be mentioned that even if lasers have almost zero étendue — which is a clear benefit from optical design point of view - the étendue is increased to a certain value by the means of the present invention. This increase of étendue is necessary to reduce the spatial coherence of the beam and consequently to reduce the speckle contrast. An important side effect of this increase of étendue is a higher safety for the eye: The light coming out of the image modulator is neither coherent nor can it be collimated again like a laser beam. On the other hand the étendue can be controlled by the size and distance of the optical parts to a fairly low value which still gives a benefit to other light sources like arc lamps or LED.

[0102] The embodiment of Fig. 3B is comparable to that of Fig. 3A except in that explicit beam expander optics 20 are missing the functionality of which is simultaneously realized by said light pre-processing optical element 30 or said phase modulator 30.

The following aspects are of importance:

[0103] Fig. 4 is a schematical and cross-sectional side view of a preferred embodiment of the light pre-processing optical element 30 or phase modulator 30 according to the present invention. Key aspect of this embodiment for the light pre-processing optical element 30 or phase modulator 30 is the provision of a liquid crystal element 34' in the form of a liquid crystal layer 34 which is sandwiched between an electrode arrangement 35 of a pair of first and second control electrodes 32 and 33. The entity formed by the liquid crystal element 34' and the electrode arrangement 35 forms the pre-processing section P of the embodiment of the light pre-processing optical element 30 or phase modulator 30.

[0104] In the embodiment of Fig. 4 the light entrance section E is formed by a first substrate 31a or substrate plate 31a and the light output section O is formed by a second substrate 31b or substrate plate 31b. In the embodiment shown in Fig. 4, the first control electrode 32 in direct vicinity to the first substrate plate 31a is formed by a single control electrode 32 set to ground potential. On the other hand the second control electrode 33 of the electrode arrangement 35 is in close vicinity to the second substrate plate 31b and formed by a plurality, array or matrix of independently controllable electrode segments 33j with j = 1, ..., M. According to the embodiments of Fig. 4 the portion of the liquid crystal element 34' directly sandwiched between the first and common control electrode 32 and a respective electrode segment 33j of the second control electrode 33 can be set to a distinct value of a wave front or phase modulation by using the dependency of the effective refraction index n_{eff} on an externally applied electrical field or electrical voltage according to

$$\varphi_j = \frac{2\pi \cdot d \cdot n_{eff}(U_j)}{\lambda}.$$

[0105] Therefore according to the arrangement of the segments 33j of the second control electrode 33 one achieves a spatially dependent distribution of the phase modulation if the voltages of the electrode segments 33j are controlled in a respective and independent manner, for instance randomly.

[0106] Fig. 4 shows a cross section of this liquid crystal cell. The phase modulator 30 comprises a liquid crystal cell. The liquid crystal fills the gap between two substrate plates 31a, 31b. An electrical field is applied between the common electrode 32 on the substrate 31a and the pattern of multiple electrodes 33i, i=1, ...M on the counter substrate 31b. All electrodes are transparent in order to transmit light. The direction of the so called director of the liquid crystal layer is aligned by alignment layers. It is not part of the present invention to describe the details of the alignment of liquid crystal layers and the realization of the electrical connections of the electrodes. This is well known by prior art (e.g. the technology of liquid crystal displays). Essential for the use in the present invention is the fact that a liquid crystal layer 34 has an effective (average) refractive index neff which is dependent from the applied voltage Ui=1, ...M across the layer. This effective (average) refractive index neff depends on the polarization direction of light as a liquid crystal layer is birefringent. It is preferred that the liquid crystal layer 34 is aligned parallel between the substrates 31a and 31b. In that case the polarization direction of linear polarized is not changed, if the polarization direction is parallel or perpendicular to the alignment direction of the liquid crystal layer 34. The phase of linear polarized light which passes the liquid crystal layer 34 is retarded by $\varphi i = 2\pi \times d \times neff(Ui) / \lambda$, where d is the thickness of the liquid crystal layer 34 and λ is the wavelength of light. By applying different voltages to each individual electrode the phase front is laterally disturbed. By changing the voltages with time Ui(t) the phase front is disturbed in time. Consequently different uncorrelated phase front patterns can be generated during a given period of time. For example, if M different phase front patterns are generated during the period of one image frame, e.g. 20ms, then the speckle contrast of a projected image is reduced by factor $\sqrt{M}$.

[0107] Figs. 5 and 6 show embodiments for light source units 10' having different realizations for the expander optics 20'.

[0108] The beam expander 20 can be realized according to Fig. 5. A negative lens expands the collimated laser beam to a certain angle and a positive lens 25 at a certain distance collimates the beam again.

[0109] Alternatively, according to Fig. 6, a diffuser 22 can be used in order to diffuse the collimated light into a certain cone angle. A second alternative is to use a diffractive optical element 23 (DOE) to expand the laser light beam. In case of a DOE an additional beam shaping is possible in order to adapt the shape of the expanded beam to the shape of the lens arrays. Also a combination of a negative lens and a diffuser or DOE can be used to expand the collimated laser light beam.

[0110] Fig. 7 is a schematical and cross-sectional side view of a preferred embodiment of the image generating unit 1' according to the present invention.

[0111] In this embodiment the illumination unit 10' comprises a light source 10 which is formed by an array of laser sources 10 and which therefore produces a laser beam or an array of laser beams as said primary illumination light L1. The laser light is received by a expander optics 20 in order to expand the primary illumination light L1 in order to achieve a complete irradiation or illumination of the following light pre-processing optical element 30 or phase modulator 30. The light pre-processing optical element 30 or phase modulator 30 in the case of the embodiment of Fig. 7 again acts as an location dependent and time-dependent phase modulator which modulates the optical phases ϕ of the laser beams or of the different cross-sectional parts of the laser beams as a function of the spatial coordinates x, y and as a function of time t. The following illumination optics 40' comprises a lens array 40 which divides by means of respective lens segments the expanded and phase modulated laser beams or laser beam into N different sub-beams by means of said respective N lens segments. By means of a following condenser lens 45 as a part of said illumination optics 40' the spatially separated sub-beams are then focussed onto a following image modulator unit 100' which comprises a respective image modulator 100.

[0112] All optical components of the embodiment shown in Fig. 7 are arranged along a common optical axis Z. Said optical axis Z is arranged perpendicularly or essentially perpendicularly with respect to the optical surfaces of said light pre-processing optical element 30 or phase modulator 30, said lens array 40 and said condenser lens 45.

[0113] Here again said illumination optics 40' comprises first and second lens arrays 40 and 41, respectively, with respective lens segments 40i, 41i. Additionally, the image modulator unit 100’ again comprises a field lens 90.

[0114] In the embodiment of Fig. 7 the light source unit 10’ comprises a plurality of laser light sources 10 in order to achieve an increased illumination of the light pre-processing optical element 30 or phase modulator 30 and further of the image modulator unit 100’.

[0115] The same holds for the embodiment of Fig. 8.

[0116] The possible use of a plurality of "n" single lasers which are incoherent with respect to each other has the advantage of further reducing the speckle contrast by $\sqrt[2]{n}$.

[0117] It might be necessary to use as light source an array (1D or 2D) of lasers in order to achieve a sufficiently high optical output power. In that case the beam expander 20 must be adapted according to Figure 7 or 8.

[0118] In case of Fig. 7 the beam expander is arranged and/or adapted in a way that each laser beam is expanded to illuminate the entire lens array.

[0119] In case of Fig. 8 the beam expander is arranged and/or adapted in a way that each laser beam illuminates only a part of the lens array 40.

[0120] In Figs. 1, 2A, 2B, 3A, 3B, 7, and 8 the arrow X along the direction Z of the optical axis indicates possible positions X1, X2, X2’, X3 at which the light pre-processing optical element 30 or said phase modulator 30 may be situated.

[0121] In each case of the embodiments light input and light output portions 401’ and 40O’ of the illumination optics 40’ are indicated in the Figs.

[0122] Fig. 9 shows a cross-sectional front view of an embodiment for the light pre-processing optical element 30 or phase modulator 30 according to the present invention. Here one has by means of the electrode segments 33j of the second control electrode 33 a sub-division of the liquid crystal element 34’ and of the liquid crystal layer 34 with respect to the optical phase modulation. In the case of Fig. 9 it has a sub-division of the liquid crystal element 34’ in matrix-form with MH columns and MV lines with a condition M = MH MV. Each segment $34_{h.v}$ of the liquid crystal element 34’ or the liquid crystal layer 34 is controlled by a respective electrode segment $33_{h,v}$ to achieve a respective phase modulation $\phi_{h,v}$ (t) in a time-dependent manner with h = 1, ..., MH and with v = 1, ..., MV.

[0123] It is preferred, but not necessarily restricted to, that the number and shape of the electrodes 33i, i = 1, ..., M is congruent to the number and shape of the lens segments on lens array 40 as shown in Figure 9. But it is also possible to increase the number of electrodes (M>N) in order to further disturb the phase front or — on the other hand — to reduce the number of electrodes (M<N) in order to simplify the realization of the electrodes and their electrical connection.

Reference Symbols

[0124]

1	illumination unit according to the present invention
1’	image generating unit according to the present invention
10	light source, coherent light source, laser light source
10’	light source unit
20	expander optics
21	negative lens
22	diffuser
23	diffractive optical element
25	positive lens
30	light pre-processing optical element according to the present invention, phase modulator according to the present invention
31a	first substrate, first substrate plate
31b	second substrate, second substrate plate
32	first control electrode
33	second control electrode
33i	electrode segment of second control electrode
34	liquid crystal layer
34’	liquid crystal element
35	electrode arrangement
40	first lens array
40’	illumination optics
401’	light input portion
40O’	Light output portion
40i	lens segment of first lens array 40
41	second lens array
41i	lens segment of second lens array 41
45	condenser lens
90	field lens
100	image modulator
100’	image modulator unit

d	layer thickness of liquid crystal layer 34
E	light entrance section
I	image
L1	primary illumination light
L1’	pre-processed primary illumination light, phase modulated primary illumination light
L2	secondary illumination light
L2’	condensed secondary illumination light
L3	tertiary illumination light
L4	projection light, image light, output light
LC	liquid crystal
n_{eff}	refraction index of liquid crystal layer 34
O	light output section
P	light pre-processing section
t	time
Ui	voltage applied to segment electrode 33i of second control electrode 33
Z	optical axis, direction of optical axis

λ wavelength of light
φ phase modulation/retardation caused by liquid crystal layer 34

Claims

1. Illumination optics (40'), in particular for an image generation unit (1'):

   - which comprises a light input portion (40I') for receiving a beam of primary illumination light (L1),
   - which is adapted and which comprises means (30, P) for independently and/or uncorrelatedly modulating wave fronts, phases or phase relation-ships of a plurality of parts or sub-beams of said beam of said received primary illumination light (L1) to thereby generate respective parts or sub-beams of pre-processed primary illumination light (L1') as respective parts or sub-beams of secondary illumination light (L2) having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other,
   - which is adapted and which comprises means for superimposing and/or recombining respective parts or sub-beams of said secondary illumination light (L2) having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other in order to thereby generate a beam of tertiary light (L3) having reduced speckle noise properties when compared to said primary illumination light (L1), and
   - which comprises a light output portion (40O') for providing said tertiary illumination light (L3) as output light,

2. Illumination optics (40') according to claim 1, which is adapted and which comprises means (40, 41, 30, P) for dividing said received beam of primary illumination light (L1) into said plurality of parts or sub-beams of said beam of said received primary illumination light (L1).

3. Illumination optics (40') according to claim 1, wherein said means (30, P) for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships is adapted for dividing said received beam of primary illumination light (L1) into said plurality of parts or sub-beams of said beam of said received primary illumination light (L1).

4. Illumination optics (40') according to any one of the preceding claims, wherein said means (30, P) for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships is provided as a light pre-processing optical element (30) and in particular as a phase modulator (30).

5. Illumination optics (40') according to any one of the preceding claims, wherein said light pre-processing optical element (30) and in particular said phase modulator (30) comprise

   - a light entrance section (E) for receiving said beam or said plurality of sub-beams of said received primary illumination light (L1),
   - a light pre-processing section (P) for pre-processing said beam or said plurality of sub-beams of said beam of said received primary illumination light (L1) in order to thereby generate a respective beam or a respective plurality of parts or sub-beams of a beam of pre-processed primary illumination light (L1') as a respective beam or as a respective plurality of parts or sub-beams of a beam of secondary illumination light (L2), and
   - a light output section (O) for providing said secondary illumination light (L2),
   - wherein said light pre-processing section (P) is adapted and comprises means for independently and/or uncorrelatedly modulating wave fronts, phases or phase relationships of said plurality of parts or sub-beams of said beam of said received primary illumination light (L1) to thereby generate said respective parts or sub-beams of pre-processed primary illumination light (L1') as said respective parts or sub-beams of said beam secondary illumination light (L2) having independently and/or uncorrelatedly modulated wave fronts, phases and/or phase relationships with respect to each other.

6. Illumination optics (40') according to claim 5, wherein said light pre-processing section (P) comprises or is formed by a diffuser, which in particular has a plate like structure and/or which is rotatable and/or movable.

7. Illumination optics (40') according to claim 5, wherein said light pre-processing section (P) comprises or is formed by one or a plurality of liquid crystal elements (34') as wave front and/or phase modulating elements.

8. Illumination optics (40') according to claim 7, wherein said liquid crystal element (34') is formed as a plate-like structure and/or as a planar structure, in particular as a liquid crystal layer (34).

9. Illumination optics (40') according to claim 8,

- wherein the arrangement formed by said light entrance section (E), said light pre-processing section (P) and said light output section (O) defines and forms an optical axis (Z),
- wherein said liquid crystal element (34') defines and forms a normal axis and
- wherein said optical axis (Z) and said normal axis are oriented parallelly with respect to each other.

10. Illumination optics (40') according to anyone of the preceding claims 7 to 9,
wherein said liquid crystal element (34') is supported and/or framed by and between a first substrate (31a) in particular forming at least part of said light entrance section (E) and a second substrate (31b) forming at least a part of said light output section (O), in particular in a parallel manner.

11. Illumination optics (40') according to claim 10,
wherein said first and/or said second substrate (31a, 31b) are formed as plate-like structures.

12. Illumination optics (40') according to any one of the preceding claims 7 to 11.
wherein said light pre-processing section (P) comprises an electrode arrangement (35) of at least a pair of first and second control electrodes (32, 33) for exerting an electric field or voltage across said liquid crystal element (34') in order to set the liquid crystal element's optical properties in a controllable manner.

13. Illumination optics (40') according to claim 12,
wherein said first control electrode (32) of said pair of said first and second control electrodes (32, 33) is formed as a single and common electrode (32).

14. Illumination optics (40') according to any one of the preceding claims 12 or 13,
wherein said second control electrode (33) of said pair of said first and second control electrodes (32, 33) is formed as an arrangement or as an array of independently controllable single electrodes (33i; i = 1, .., M).

15. Illumination optics (40') according to claim 14,
wherein said arrangement or said array of said independently controllable single electrode segments (33i; i = 1, ..., M) of said second electrode (33) defines an according arrangement or an according array of liquid crystal element segments (34i; i = 1, ..., M) of said liquid crystal element (34') or of said liquid crystal layer (34).

16. Illumination optics (40') according to any one of the preceding claims,
which is adapted and which comprises means for receiving said secondary illumination light (L2) from said light pre-processing optical element (30) or phase modulator (30) and for generating and providing condensed secondary illumination light (L2') as tertiary illumination light or output light (L3).

17. Illumination optics (40') according to any one of the preceding claims,
comprising a first lens array (40) of lens segments (40j; j = 1, ..., N) which is arranged at the light output section's side of said light pre-processing optical element (30) or phase modulator (30) and which is adapted and comprises means in order to receive said secondary illumination light (L2) and in order to generate and provide an according number of N sub-beams of said secondary illumination light (L2) as said tertiary illumination light (L3) or a pre-form thereof.

18. Illumination optics (40') according to any one of the preceding claims,
comprising a condenser lens (45) which is arranged in order to receive said sub-beams of said secondary illumination light (L2) and which is adapted in order to focus said sub-beams of said secondary illumination light (L2) in order to generate and provide said tertiary illumination light (L3).

19. Illumination optics (40') according to claim 18,
comprising a second lens array (41) of lens segments (41j'; j' = 1, ..., N') which is arranged at the light output section's (O) side of said light pre-processing optical element (30) and between said first lens array (40) and said condenser lens (45).

20. Illumination optics (40') according to claim 19,

- wherein said lens segments (40j; j = 1, ..., N; 41j'; j' = 1, ..., N') of said first and said second lens arrays (40, 41) respectively are formed and arranged in a one-to-one correspondence to each other, and
- wherein according to said correspondence of said lens segments (40j, 41j') of said first and said second lens arrays (40, 41), respectively, a sub-beam of said second illumination light (L2) generated by a given lens segment (40j) of said first lens array (40) and its profile are imaged to a respective corresponding lens segment (41j') of said second lens array (41).

21. Illumination unit (1), comprising

- a light source unit (10') for generating and providing primary illumination light (L1) and
- an illumination optics (40') according to any one of the preceding claims 1 to 20 for receiving said primary illumination light (L1) and for gen-

erating and providing pre-process primary illumination light (L1') as secondary illumination light (L2) having a modulated wave front and/or phase or phase relationship when compared to said primary illumination light (L1).

22. Illumination unit (1) according to claim 21, wherein the liquid crystal element (34') of said light pre-processing optical element (30) is adapted and arranged in order to be completely irradiated by said primary illumination light (L1).

23. Illumination unit (1) according to any one of the preceding claims 21 or 22, wherein said light source unit (10') comprises at least one coherent light source (10).

24. Illumination unit (1) according to claim 23, wherein said coherent light source (10) is a laser light source.

25. Illumination unit (1) according to any one of the preceding claims 21 to 24, wherein said light source unit (10') comprises beam expander optics (20) which is adapted and which comprises means in order to expand said primary illumination light (L1) for a complete irradiation of said liquid crystal element (34') of said light pre-processing optical element (30).

26. Image generation unit (1'). corresponding

- an illumination unit (1) according to any one of the preceding claims 21 to 25 and
- an image modulator unit (100') which is adapted, arranged and which comprises means for receiving illumination light (L3) and for generating and providing output light (L4) which is representative for an image (I).

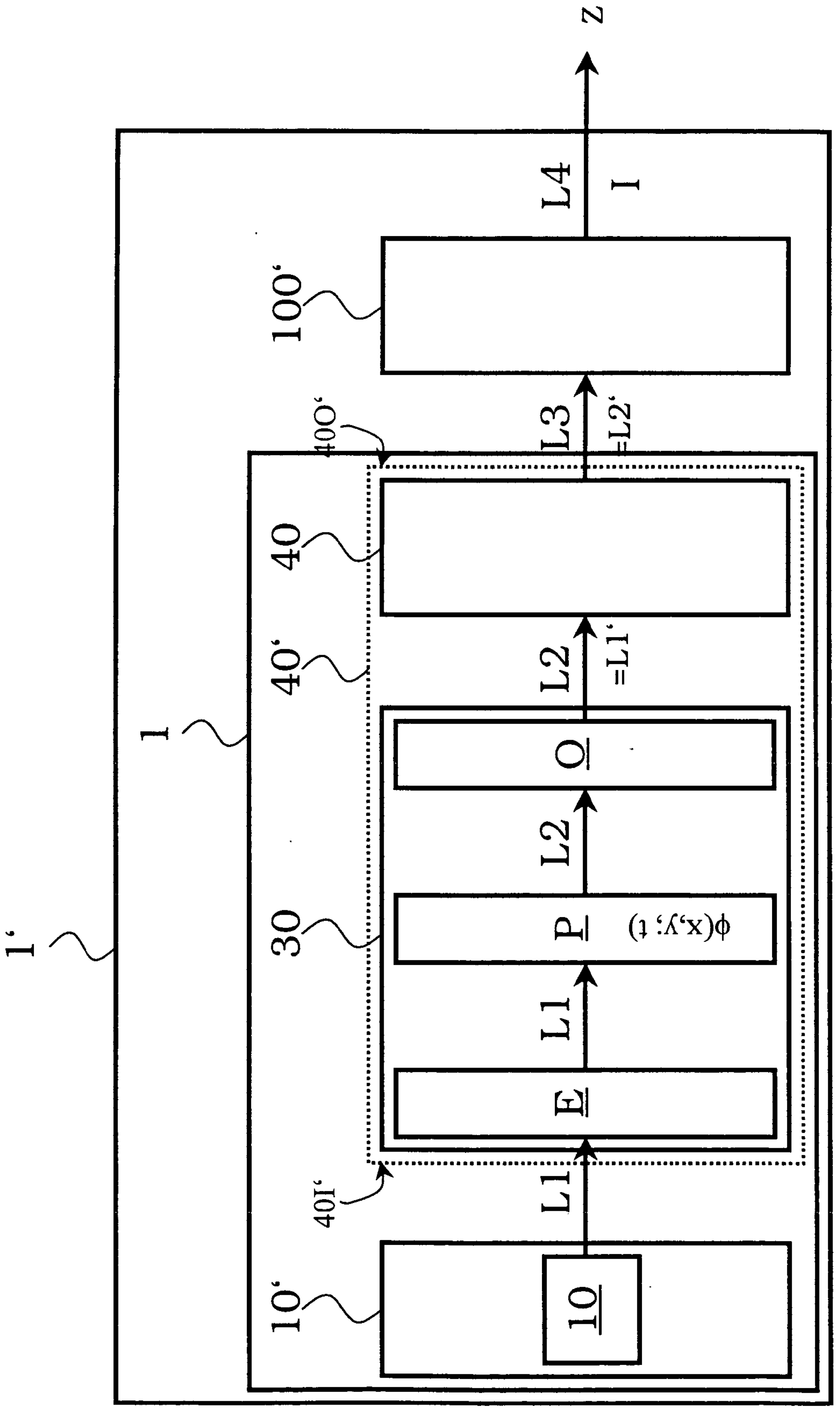


Fig. 1

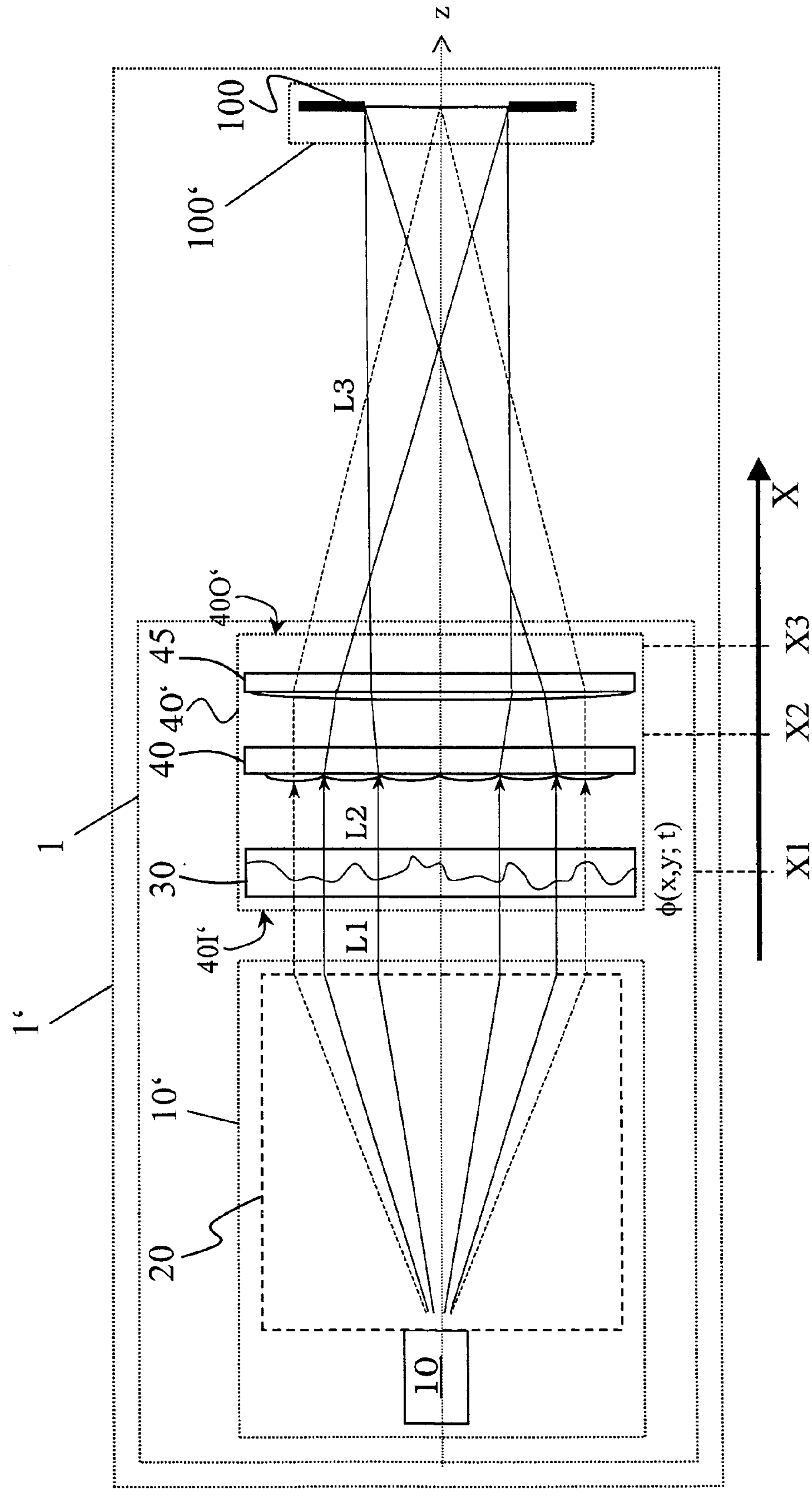


Fig. 2A

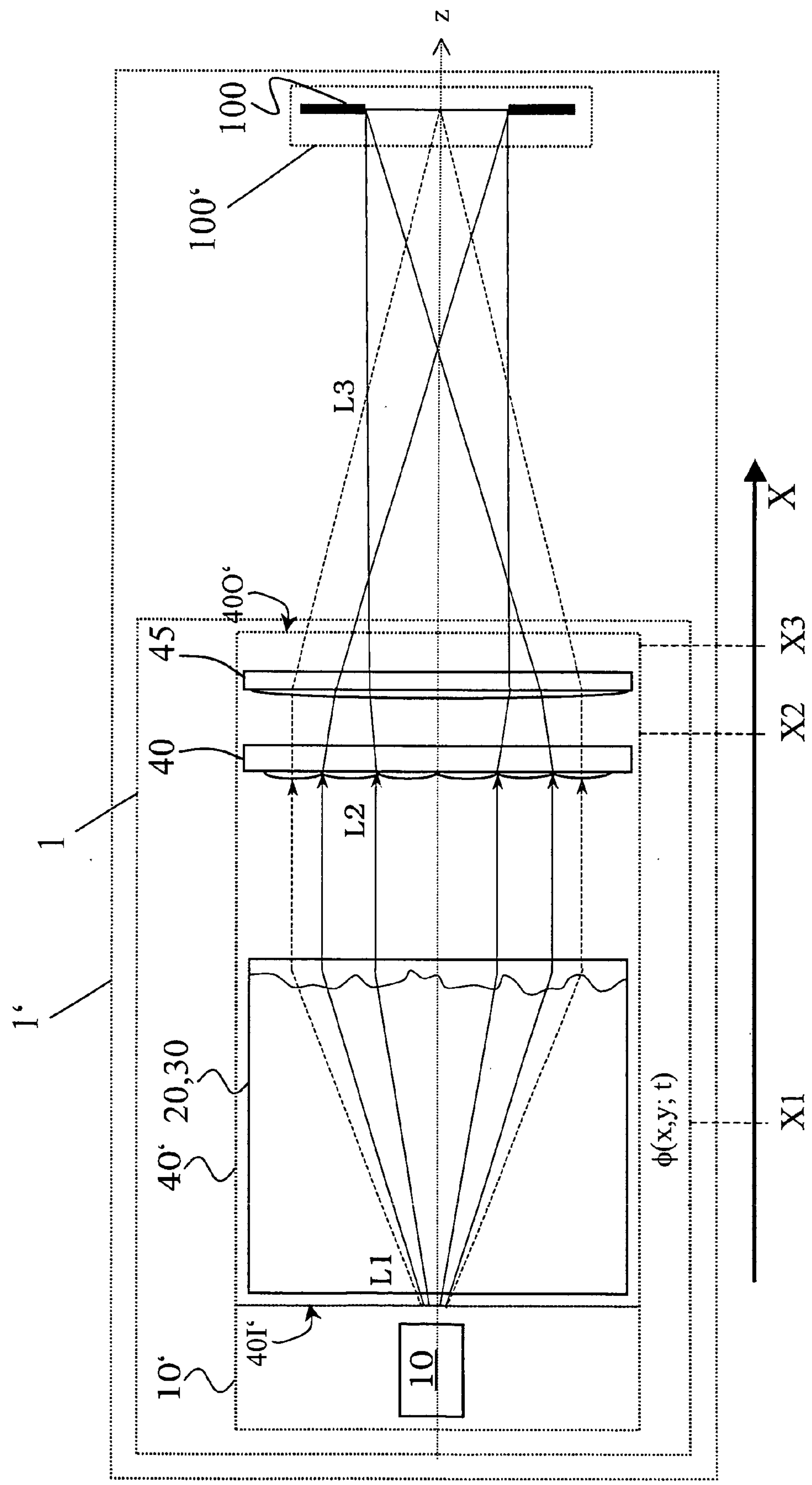
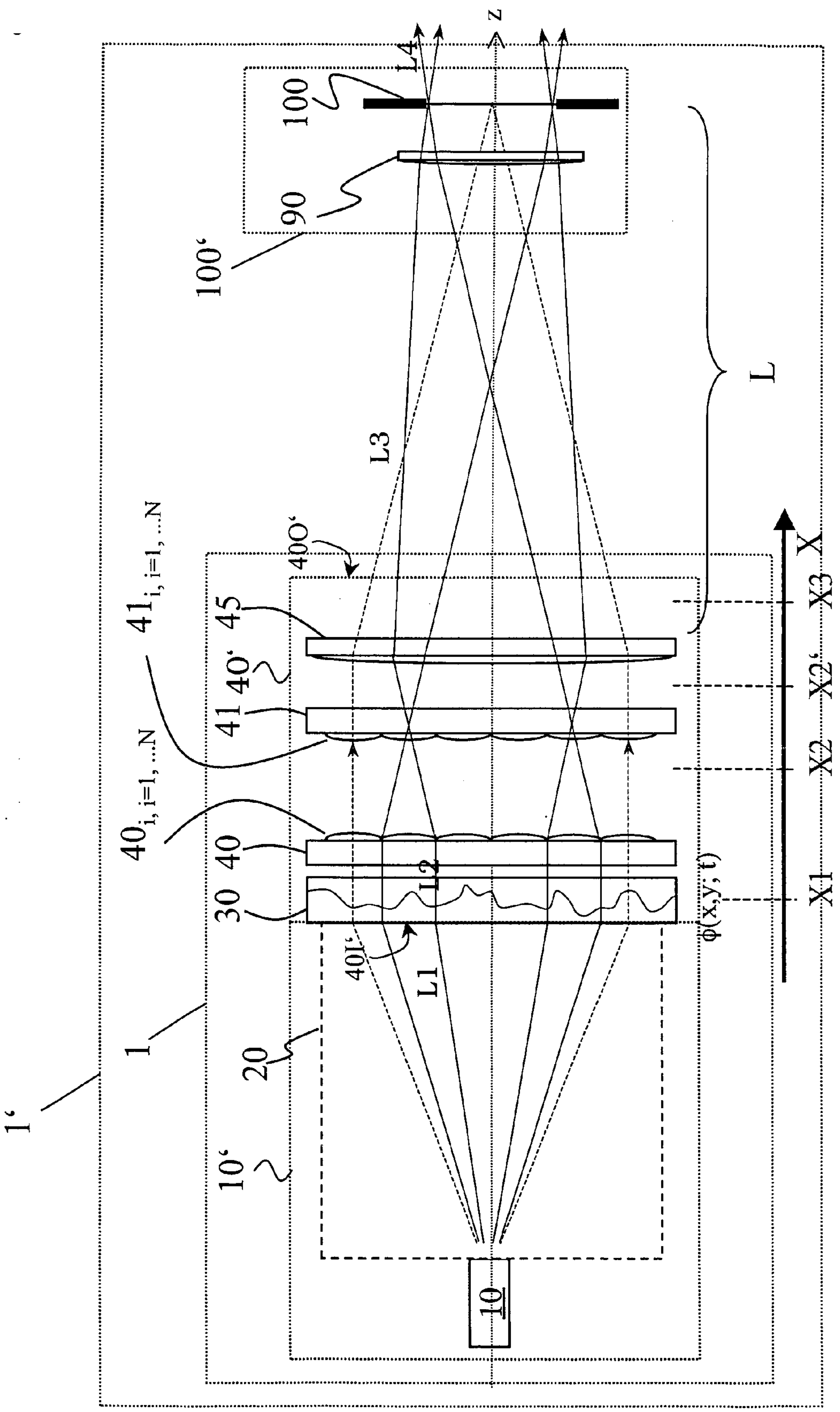


Fig. 2B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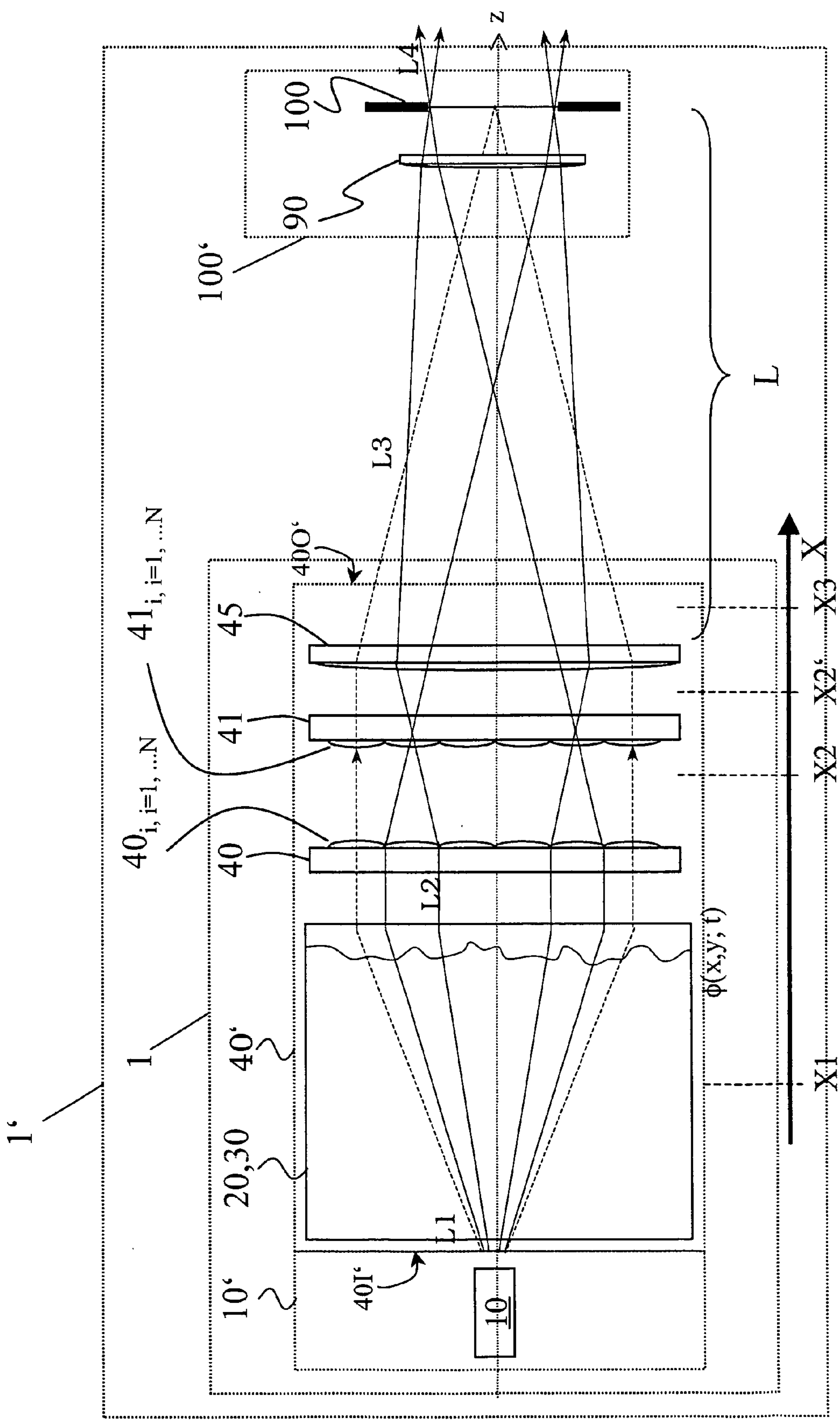
10'
10
20
30
40
41
40'
45
400'
40I'
40i, i=1, ..N
41i, i=1, ..N
L1
L2
L3
L4
L
90
100
100'
z
X
X1
X2
X2'
X3
φ(x,y;t)

Fig. 3A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10‘
10
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L1
20,30
40‘
φ(x,y;t)
L2
40
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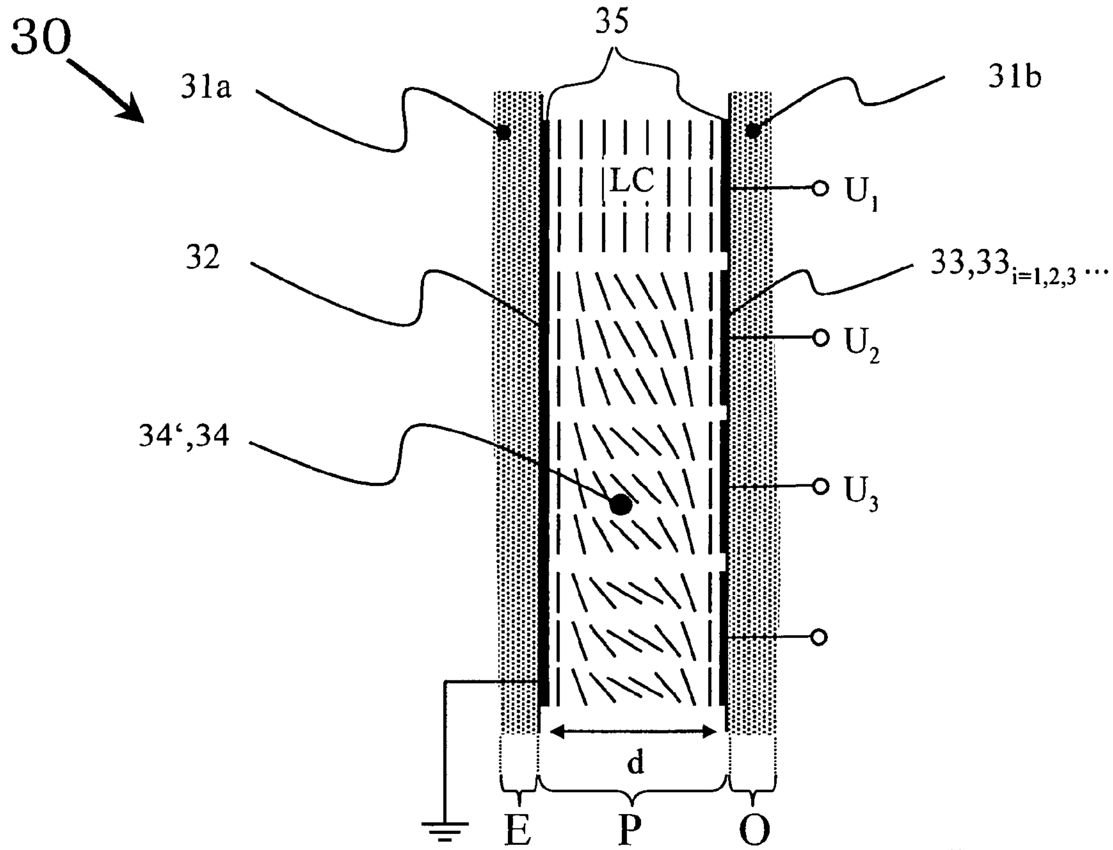
41
41i, i=1, ...N
45
40O‘
L3
L
100‘
90
100
L4
z
X1
X2
X2‘
X3
X

Fig. 3B



Phase retardation/modulation:

$$\phi_1 = \frac{2\pi \cdot d \cdot n_{eff}(U_1)}{\lambda}$$

$$\phi_2 = \frac{2\pi \cdot d \cdot n_{eff}(U_2)}{\lambda}$$

$$\phi_3 = \frac{2\pi \cdot d \cdot n_{eff}(U_3)}{\lambda}$$

...

n_{eff} = *effective refractive index of the LC for polarized light*

λ = *wavelength of the light*

Fig. 4

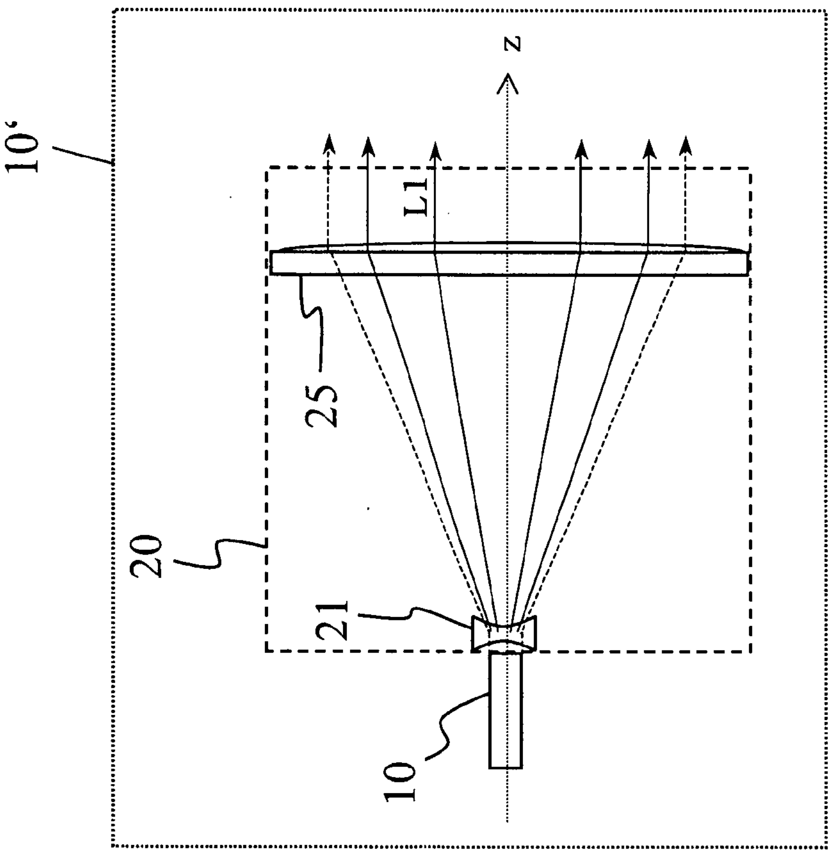


Fig. 5

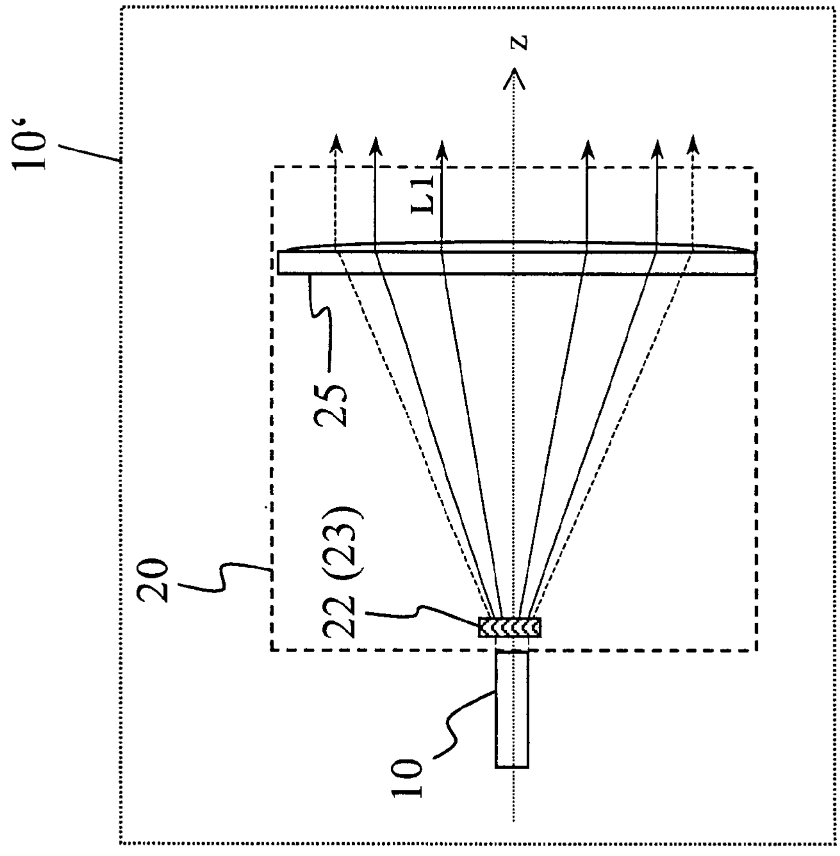


Fig. 6

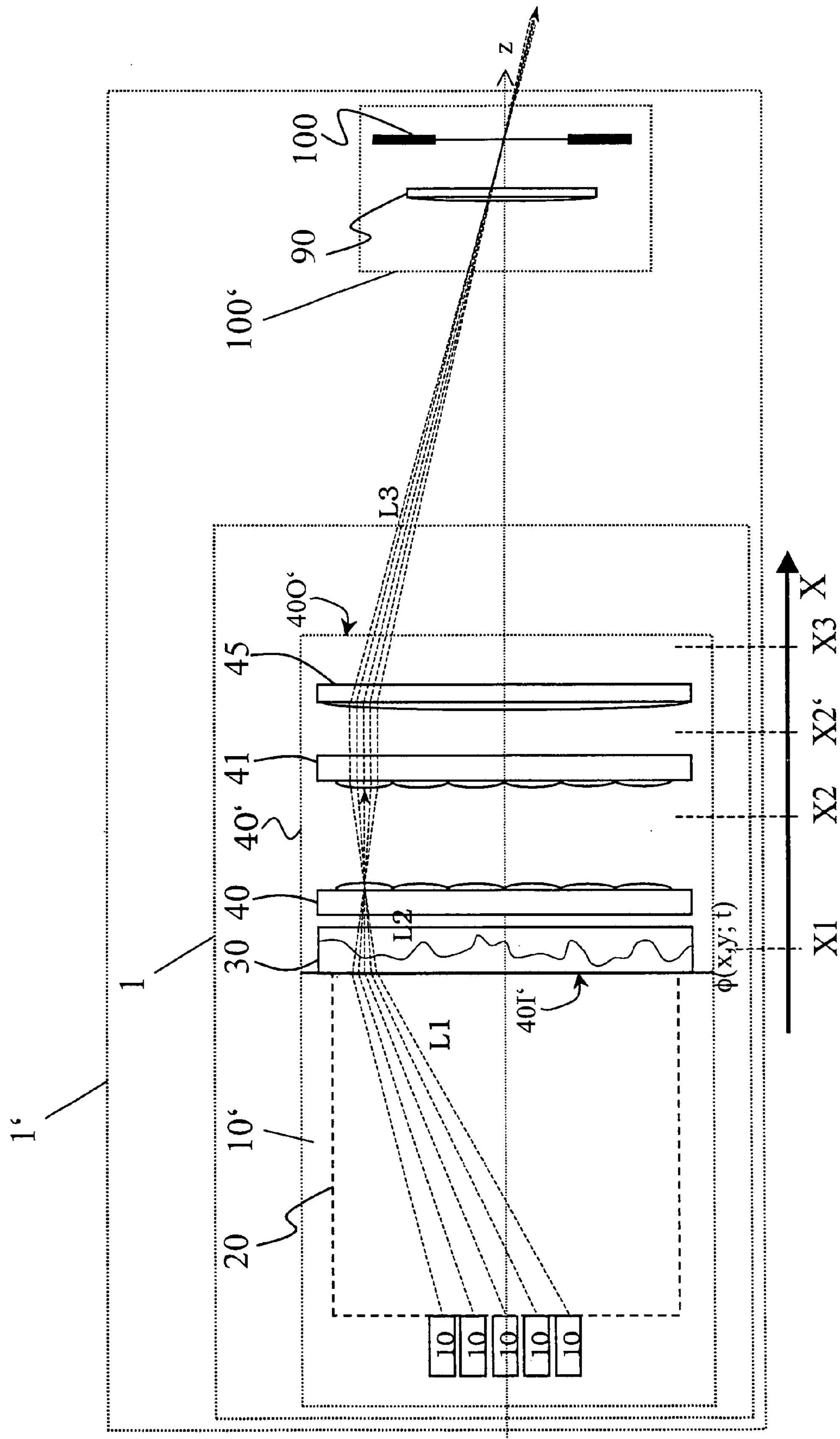

z
100
90
100'
L3
400'
45
41
40'
40
30
L2
1
1'
10'
20
L1
40I'
φ(x,y; t)
10
X
X1
X2
X2'
X3

Fig. 7

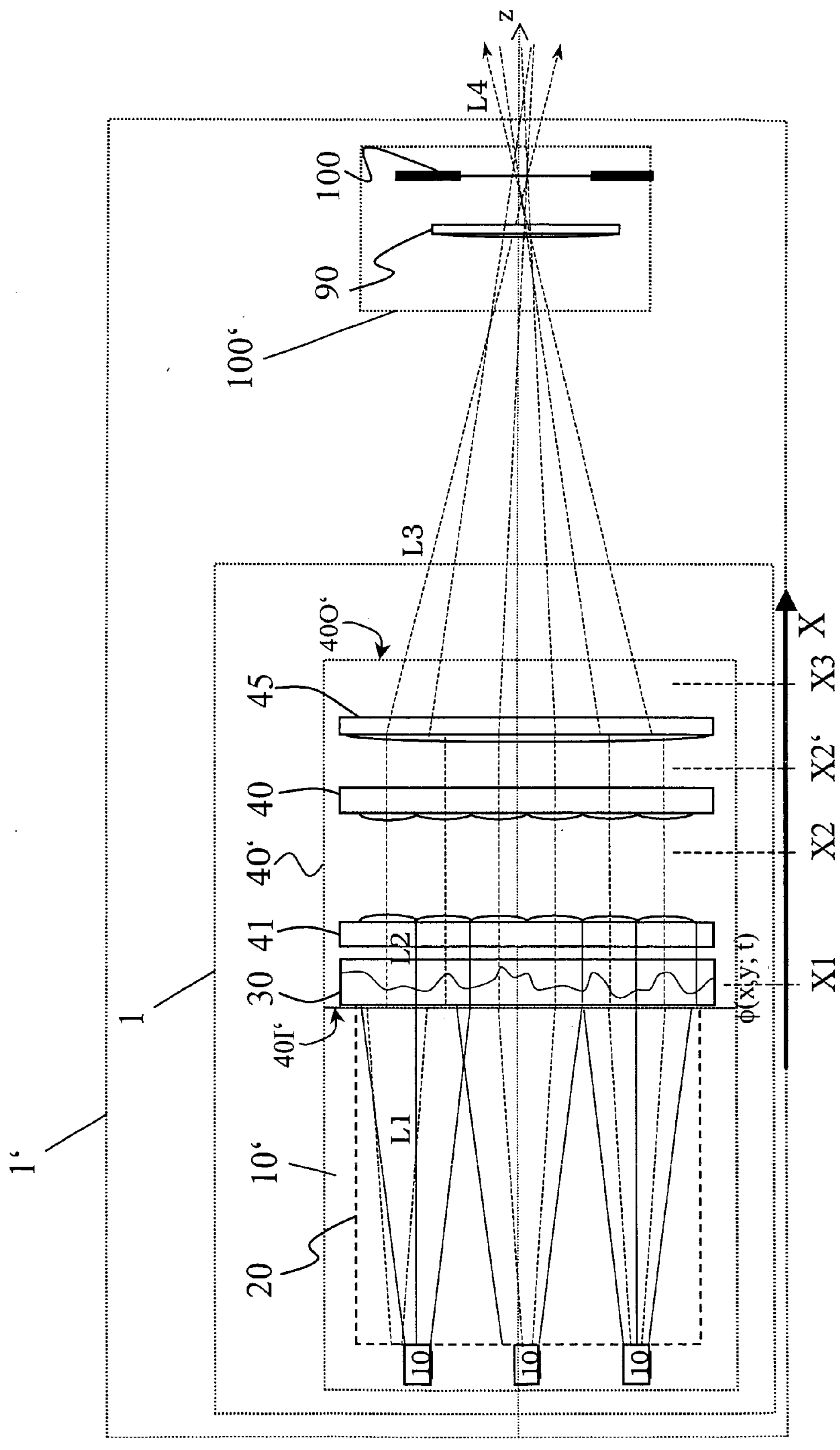
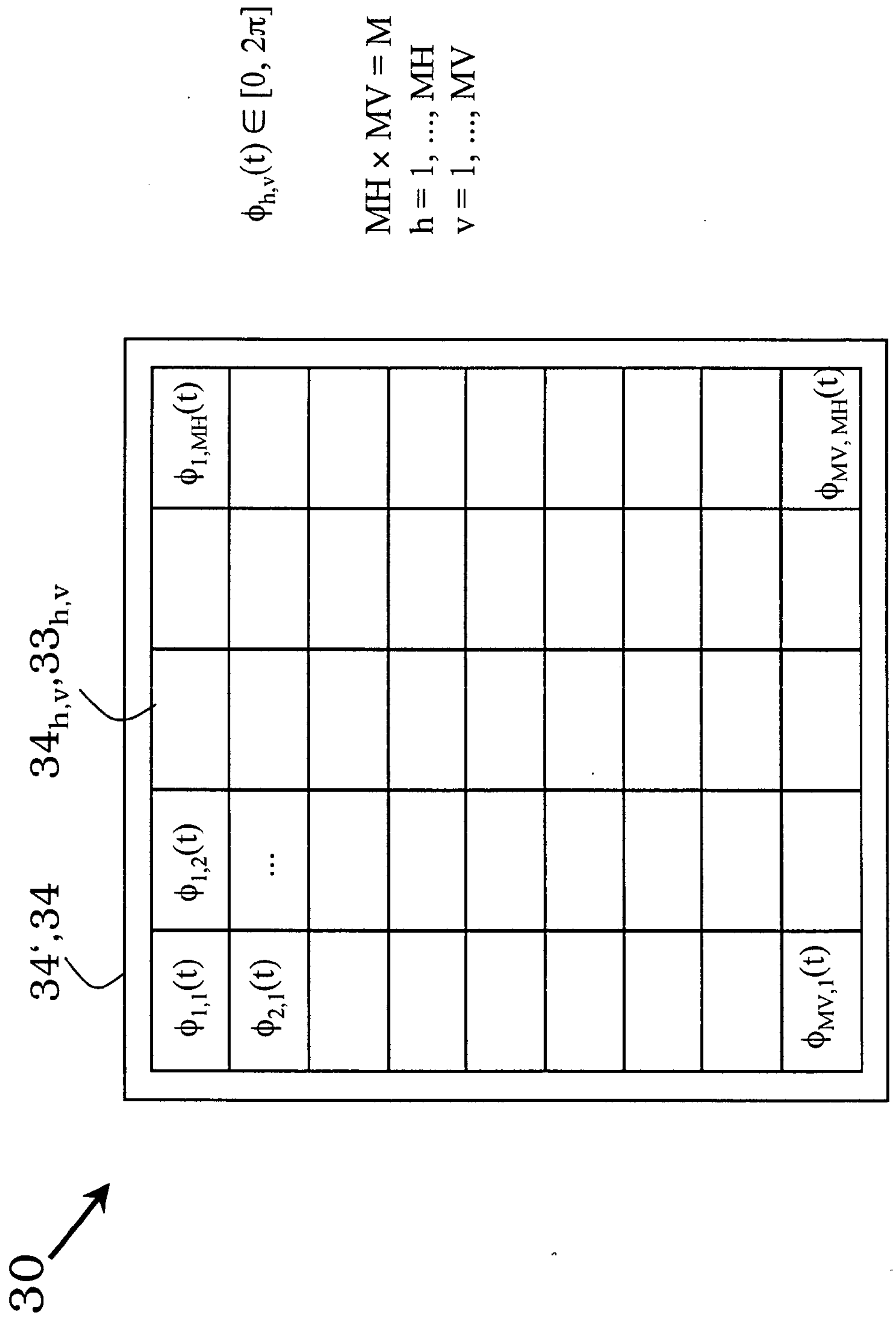

1'
1
10'
20
10
10
10
L1
30
40I'
41
L2
40'
40
45
40O'
L3
100'
90
100
L4
z
φ(x,y; t)
X1
X2
X2'
X3
X

Fig. 8



φh,v(t) ∈ [0, 2π]
MH × MV = M
h = 1, ..., MH
v = 1, ..., MV
34',34
34h,v,33h,v
φ1,1(t)
φ1,2(t)
φ1,MH(t)
φ2,1(t)
...
φMV,1(t)
φMV, MH(t)
30

Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 05 01 2806

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 1 328 128 A (EASTMAN KODAK COMPANY) 16 July 2003 (2003-07-16) * paragraph [0017] - paragraph [0062]; claims 1-36; figures 1-10 *	1-6, 16-26	H04N9/31 G02B27/48
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X	US 2004/008399 A1 (TRISNADI JAHJA I) 15 January 2004 (2004-01-15) * paragraph [0044] - paragraph [0051]; figure 3 *	1-12,16, 18,21, 23-25	
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The present search report has been drawn up for all claims

4

Place of search	Date of completion of the search	Examiner
Berlin	2 November 2005	Jacobs, A

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